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Plant Biotechnology in India - Seeds of Survival

Latha Rangan[1] and Vibha Dhawan[2]

1 Department of Biotechnology, Indian Institute of Technology Guwahati, Guwahati, INDIA

lrangan@iitg.ernet.in

2 Bioresources and Biotechnology Division, The Energy and Resources Institute, Indian Habitat Centre, Lodhi Road, New Delhi, INDIA

ABSTRACT:
Plant biotechnology offers tremendous potential to address the challenge of providing food security to India in years to follow. Other benefits of using plant biotechnology are precision, lower research costs, improved quality of life, reduced consumer prices, and the delivery of a broad range of biotechnology products. India has the potential to break through the crop yield ceiling and overcome the deadlock in crop production. Unfortunately, even with the technologies available, a large gap still exists between potential and actual yields, as there are concerns about the value and safety of food products derived using theses technologies especially genetic engineering. These impede with the progress of the nation further exasperated by trade policy. On contrary, these tools can offset the negative consequences of agricultural intensification and can decrease environmental degradation but to make further progress the polarized views and extended debate over the cultivation of genetically modified crops will need to be set aside in favour of decision-making and action. This action requires political will. Scientists, economists, politicians, farmers, consumers and conservationists need to work together to use all of the available means, including plant biotechnology, to meet the needs of more than one billion growing population and to prevent environmental degradation. It is necessary to proceed prudently and cautiously, as with any new technology. These are some of the issues that have been tackled in the current paper. However, authors also opine that it would be naïve to suggest that biotechnology will solve the food problems, but there is clear evidence that it provides a technical platform to certain problems and should be adopted.

Keywords: Agriculture, Biotechnology, Genetic modification, Plant breeding

INTRODUCTION

The last four decades has witnessed an increase in world population rate of 2.2% whereas food production increased only at the rate of 2.8% [1, 2]. These trends need to be reversed, as the consequences will be a dramatic. World population is likely to reach 8 billion from present level of 6 billion by 2025 [3] and rising standards will put more pressure on food grains. As people move into the higher income brackets, they consume more livestock products such as meat, milk and eggs. These products are produced at higher consumption levels of feed grains. Thus, food grain requirements are likely to increase by 70% by 2025 due to population increase and changing food habits [4]. There are no additional lands for food production. Water is being withdrawn from agriculture for domestic and industrial purposes, labour is shifting from agriculture to industry, and concerns about the overuse and misuse of chemicals in agriculture are being heard everyday. Some of the best agricultural lands are being taken out of production due to urbanisation and industrialisation. Thus, we will have to produce additional food from less land, with less water, less labour and reduced chemical use. To meet this challenge we need crop varieties with higher yield potential, with resistance to diseases and insects and with tolerance to stresses such as drought, salinity and unfavourable temperatures.

Agriculture is the most important economic activity in India that accounts for nearly 65% of the country's employment, 26% of the total GDP and nearly 20% of total export earning [5]. Agriculture sector not only serves the backbone for Indian economy but also livelihood security for about 700 million of our one billion populations. Agriculture, therefore, is and will continue to be central to all strategies for planned socio-economic development of the country. Despite major advances in agriculture and food production during last four decades, thousands die of starvation and hunger in many parts of the country. Agricultural improvement to raise food production to the levels necessary is an urgent priority and innovative technologies are essential for this transformation in India. Recent breakthrough in biotechnology has the promise to help these challenges and the potential to resolve many of the problems affecting crop and livestock production while having the scope to ensure that the country's enormous biological diversity is maintained.

BENEFITS OF BIOTECHNOLOGY

Biotechnology is becoming a valuable tool that can improve our quality of life in many ways, both now and in future. Among many uses of biotechnology, food and agriculture applications are unquestionably of

particular interest to humankind. Biotechnology has the potential to deliver significant benefits to:

- Consumers, who seek better quality, better tasting and more nutritious food with improved protein quality.
- Farmers who want more efficient methods to grow crops with less impact on the environment, and to reap more bountiful harvests from existing land.
- Developing countries seeking solutions to help feed a growing population.

Increased local food production in developing countries can contribute to lower food costs and enhanced food security. The world has desperate need for a wide range of crops which combine low input and low environmental impact with high yield, high quality and the 'brave new world' of genetic engineering is out to help plant breeders to produce them in a race against time. The new tools in plant biotechnology that has been put to applied breeding aspects and highly successful are;

1. Plant tissue culture

Micropropagation, an essential component of plant biotechnology by which thousands of identical plants can be produced by culturing plant tissues or organs under aseptic or germ free conditions.

Greater output, economy of time and space, freedom from seasonal constraints, clonal uniformity, and disease-free nature of regenerants are the major advantages that microprogataion has over conventional methods of propagation. The technique is ideal for species where

- traditional methods of propagation are inadequate to meet the demand of planting material
- marked variation exists in natural population and productivity can be significantly increased by cloning superior individuals
- viruses, can be eliminated by culturing the shoot meristem, thereby maintaining pathogen free stock by routine micropropagation.

Tissue culture has been successfully employed for multiplication of large number of medicinal and aromatic plants, ornamental flowering plants, fruit and vegetables, cash crops and agro-forestry species. To bridge the gap between research and field, the Department of Biotechnology (DBT), Government of India has created micropropagation facility at TERI where the entire infrastructure required for tissue-cultured plants, are available (Box 1) with an annual capacity of over 2 million plants.

2. Molecular markers

Heritable traits that can be assayed are referred to as markers and are of many different kinds. In general molecular markers consist of specific molecules, which show easily detectable differences among different strains of a species or among different species. Several types of DNA sequences provide a large number of valuable markers that can be used to map their locations in the chromosomes of various species. Significant among them is the marker-assisted selection (MAS). After markers have been developed for a crop and they have been mapped to specific traits, it is possible to use these markers for quick, accurate screening of lines for the traits of interest.

Marker assisted selection has potential for the genetic improvement of traits that are otherwise tedious by conventional breeding procedures. Progress in MAS breeding is being achieved mainly in the area of disease resistance. Progenies were developed from crosses with parents in various crop species that carry different resistances. The aim was to pyramid resistances. An example of MAS breeding program in rice has been cited in Box 2. However, MAS is also suitable for specific breeding aims such as:

- for gene pyramiding (monogenic and polygenic resistance)
- for the identification of homozygous lines
- for early screening of traits which can usually only be evaluated at a late developmental stage (mildew, fruit quality and fruiting behaviour).

3. Functional genomics

An essential aspect of functional genomics and the post genomics era will be "allele mining" helping in the development of more desirable varieties of crop by isolating certain qualities. Allele mining exploits the DNA sequence of one genotype to isolate useful alleles from related genotypes. Allelic variation is the raw material of plant breeding.

Through sexual hybridization, breeders exploit the molecular diversity of their crop to create improved allelic combinations with enhanced performance. The international project to sequence the genome of certain crop species will make allele mining possible for all genes of important crops and possibly related generas. One among many applications of this sequence information will be to devise rapid and inexpensive PCR strategies to isolate useful alleles from a wide range of cultivars, related species and genera.

This capability will be important for giving breeders direct access to key alleles conferring;

- resistance to biotic stresses

- tolerance of abiotic stresses
- greater nutrient use efficiency
- enhanced yield, and
- improved quality, including human nutrition.

This approach to allele mining is already available because of existing sequence databases but will be greatly enhanced when genome wide sequencing of different crop provides both the sequence and the physical map location of each gene to the public domain.

THE HISTORY AND ART OF GENETIC MODIFICATION

Genetically modified plants are created by the process of genetic engineering that allows scientists to move genetic material between organisms with the aim of changing their characteristics. Exactly five decades ago, Watson and Crick decoded the structure of DNA (deoxyribose nucleic acid), which set the revolution, and a whole new era of modern biology. Their findings proved that all organisms are composed of cells that contain DNA molecules. Molecules of DNA form units of genetic information known as genes. Each organism has a genetic blueprint made up of DNA that determines the regulatory functions of its cells and thus the characteristics that make it unique.

Prior to genetic engineering, the exchange of DNA material was possible only between individual organisms of the same species. With the advent of genetic engineering in 1972, scientists have been able to identify specific genes associated with desirable traits in one organism, and transfer those genes beyond the boundaries of species into another organism. For example, genes from bacteria, viruses, or animals may be transferred into plants to produce genetically modified plants having changed characteristics. This method, therefore, allows mixing of genetic material among species that cannot otherwise breed naturally.

Today, the gamut of accumulated knowledge in biology is immense and far more extensive than any individual can assimilate. The discovery of DNA double helix has been the major influence behind such a dramatic change. It is such an important discovery that it can open up new avenues for lot more exciting discoveries, leading into the next century. The finding was so fundamental to uncovering the inner sanctums of life that much of biological research today is still building on it.

In the early 1990s, the first transformed crops were produced using modern biotechnology as a result of the researches done in the 1970s and 1980s. Modern biotechnology, referred to as genetic modification (GM) or genetic engineering (GE), allows the removal of individual genes from one species and inserting them into another without the need for sexual compatibility [6].

GENETICALLY MODIFIED CROPS - CASE FOR SCIENCE AND SENSE

Latest figures on food crisis in India by the UN Food and Agriculture Organization (FAO) and World Food Programme (WFP) reports that nearly 360 million people are officially living below the poverty line of which as many as 50 million are victims of starvation.

The United Nations Development Programme's Human Development Report 2001 highlights the fact that many developing countries could reap great benefits from genetically enhanced crops (GEs) and other organisms. It stresses the unique potential of genetic engineering techniques for creating virus resistant, drought tolerant and nutrient-enhanced crops, while acknowledging that there are environment and health issues that need to be addressed. Genetically modified crops could significantly reduce malnutrition, which still affects more than 800 million people worldwide, and would be especially valuable for poor farmers working on marginal lands in India and its sub-continents.

High input (developed country style) agriculture incurs high costs for agrochemical and water. Biotechnology-based solutions could reduce the demands for these resources [7]. This approach could also reduce the deleterious effects of diseases and weeds, thus promoting sustainable agricultural production [8].

Several Indian states are already putting in place structures and capacities for research and development in biotechnology under the umbrella and network of DBT, Government of India. Genetic modification is an accurate and effective way of enhancing traditional methods of selective breeding so as to achieve more desirable characteristics in plants more quickly.

Swaminathan [9], chief architect of India's Green Revolution in his article entitled "An Evergreen Revolution", emphasized that agricultural biotechnology in synergy with emerging technologies could be the solution to famine, environmental degradation and poverty rooted in the principles of ecology, economics and ethics. Judicious exploitation of biotechnology can boost rural incomes and thus improve the purchasing power of a marginalized section of developing societies and hold promise for fostering an ever-green revolution in farming.

Does Indians have the choice freely to sit down to a complete GM meal? As the DBT, Government of India set the guidelines for crop trials in future; we look into the science and sense of GM crops and all that is relevant to Indian scenario (Box 3).

SCOPE

To meet the growing domestic and export needs, India will have to produce an additional 5-6 million tones of food grains annually [10, 11]. Since the amount of arable land cannot really be increased, the existing land should be made to produce more in an eco-friendly, cost effective and sustainable manner. This situation unquestionably calls for an integrated approach for sustainable agricultural development, as no single option would provide the answer. One of the solution scientists agrees globally, could be provided by improvements in crop productivity brought through biotechnological interventions in plants.

Crop biotechnology, one of the many tools of agricultural research and development, offers many benefits for agriculture in India and offers new opportunities for integrated pest management (IPM). The technology is embedded in seed, means that it is a user-friendly technology, which fits well with the cultural practices of Indian farmers and is easier to transfer than methods that require elaborate techniques or machines. The genetically enhanced crops already being grown require fewer pesticide applications and less tilling of the soil, thereby causing less erosion [12]. Most importantly the productivity is increased. Research into the production of disease-resistant rice and wheat; improved productivity of fruits and orchards and crops that tolerate salt and desiccation are of particular importance for India [5].

Some current applications of plant biotechnology include:

- Developing plants those are resistant to diseases, pests, and stress.
- Keeping fruits and vegetables fresh for longer periods of time, which is extremely important in tropical countries?
- Producing plants that possess healthy fats and oils.
- Producing plants that have increased nutritive value.
- Producing soybeans with a higher expression of the anti-cancer proteins naturally found in soybeans.
- Developing a whole range of higher value added feed.
- Other applications such as lignin modification in trees that will make possible much higher fiber extraction rates in the paper and pulp industry.
- Producing new substances in plants, including biodegradable plastics, and small proteins or peptides such as prophylactic and therapeutic vaccines.

Over the past decade, the application of biotechnology to the problems in world agriculture has yielded significant productivity gains to the producers. Various programmes of the Department have been directed in this direction. With advancements in GM technologies, these benefits are expected to increase in Indian scenario.

The scope for the genetic enhancement for useful traits and quality will be evident from the following examples that have been supported under the network of DBT and other funding agencies;

Rice is the most important crop in India. The crop is sensitive to many disease and pests, which poses serious problems to commercial and subsistence farmers. Transgenic technology has been standardized and found to be most amenable in rice. Research using genetic engineering shows great promise for the development of rice varieties resistant to rice tungro virus, sheath blight and bacterial blight. Insect resistant transgenic rice was developed through introduction of a modified endotoxin gene of Bt. Further bioassay of putative transgenics and their progeny for expression of Bt gene is being carried out. Molecular constructs have been made both for insect and viral resistance. Studies have been conducted to transform IR-50 rice plants with proline gene to make it more tolerant to salinity. For tagging genes for leaf folder (LF) resistance in rice, two RAPD markers linked to a major gene of LF resistance has been identified. Based on these markers sequence characterized amplified regions (SCAR) primers have been developed. For tagging genes for brown plant hopper resistance in rice, several RAPD and SSR markers for BPH resistance have been identified. Also conversion of a dominant RAPD marker AJ9 to a co-dominant STS marker done and this marker is used in the selection of genotypes for BPH resistance.

Wheat is an important crop in many states of India and is eaten three times a day. Under the wheat network project different approaches were used to develop molecular markers for tagging genes with quality traits. Improved and better varieties were developed with enhanced tolerance to diseases, pests, and physical stresses. In a joint effort by scientists from Directorate of Wheat Research Institute, Karnal, efforts were undertaken to widen genetic base of wheat

and improve quality traits, which will have a significant effect on the lives of many people in India. Regeneration protocols were developed for Triticum system and to improve malt barley for northern plains. Molecular markers were used to detect adequate polymorphism and were linked to three traits (pre-harvest sprouting, protein content and grain size). Markers were also linked to protein content and grain size. Wheat was transformed with HVA1 to confer stress resistance. All the transgenics have been characterized at the molecular level for gene integration.

Mustard oil is the second most important oil seed crop in India after peanuts. GM Mustard is transformed with DNA (gene material) drawn from a number of bacteria, mainly to make it resistant to glufosinate, a broad-spectrum herbicide (chemicals used to kill weeds). Pro-Agro Seeds India Private Limited, the Indian arm of Aventis with PGS, a Belgian company, is attempting to introduce this genetically modified mustard in India. It is claimed that gene modification of mustard will help increase the production of the crop. A bacterial gene that detoxifies the broad-spectrum herbicide glufosinate is transferred to GM rapeseed/mustard so that the plant is not affected by the herbicide. This is done along with another gene to ‘switch on’ the tolerance gene, as well as male fertility and fertility restorer genes. In another project on development of molecular methods using barnase and barstar genes for hybrid seed production, in mustard transformation of *B. juncea* cv Varuna with constructs has been initiated. A number of transgenics have been developed with different barstar constructs and plants were selected in vitro, on herbicide barstar. Constructs have been designed in which influence of 35 S promoters is limited and transgenics with barnase gene showing male sterile flowers have been obtained.

Cotton - Good example were the smallholder farmers have benefited from the tools of biotechnology is the case of Bollgard insect protected cotton which have increased the yield of cotton in India by an average of 80% [13] percent using fewer insecticide sprays per season and generating a greater income (Table 1). The seeds of Cotton, the first ever-commercialized GM crop in India have gone on sale in the Indian market effective from April 2004.

For developing *Vigna mungo* plants with yellow mosaic virus resistance, coat protein gene in sense orientation and replicas gene in both sense and antisense orientation has been cloned. The binary vector has been mobilized into *A. tumefaciens*. Transformation and selection of transformed plants is in progress.

The above are a few examples of the work in progress in improving through conventional and molecular breeding techniques quantity and quality in important food crops. Consumer confidence based on an appreciation of the scientific evidence and the regulatory checks and balances will ultimately decide whether or not genetically modified foods will make a significant contribution to feeding the 8 billion people who are likely to inhabit our planet by 2020.

Marker-aided selection and transgenic approaches are two powerful tools to accelerate plant breeding to produce crop varieties with improved nutritional traits and qualities. An intelligent integration of Mendelian and molecular breeding techniques will help to enhance the nutritive value of staples. By integrating pre-breeding in laboratories with participatory breeding in farmer's fields, it will be possible to breed location specific varieties and maintain genetic diversity in crop fields [14].

SECOND GENERATION OF GE CROPS

The second generation of GE crops is already in the pipeline. These plants contain the so-called "output traits” which will have more obvious advantages to consumers. Some of the examples are cited in the following paragraphs.

I. Vitamin A supplemented food crops

The FAO estimates that 124 million people suffer from vitamin A deficiency and those 250,000 people become blind every year because of the low level of this essential vitamin in their diet. The Indian population, as a whole, has lower than recommended intakes of vitamin A, mainly as a result of the vegetarian dietary habits. The vitamin A intake in India is well below the government’s recommended daily intake levels (RDI), which in and of themselves is conservative as compared to those identified for the USA [15].

Although all socio-economic classes of the population are at risk, the problem is particularly critical among the poor and among the children, where vitamin A deficiency contributes to a 10-20% increase in mortality. A WHO estimate concludes that nearly 3 million children suffer from night blindness alone, due to vitamin A malnutrition. The problem also affects their mothers.

1. Golden rice

A promising development in the field of genetic engineering is the success in breeding a nutritionally

enriched rice variety now popularly referred to as `golden rice'. This genetically modified rice contains genes that produce high levels of beta-carotene and related compounds, which are converted in the human body into the crucially needed vitamin.

There is a strong and justifiable demand to make these transgenic plants available to farmers in developing countries, especially to combat premature death and blindness arising from vitamin A deficiency. Vitamin A deficiency (VAD) causes more than a million childhood deaths each year and is the single most important cause of blindness among children in developing countries.

Rice plants do produce caratenoid compounds (that our body converts into Vit-A) but only in the green parts of the plant and not in the part of the grain normally eaten. Dr Ingo Potrykus and Dr Peter Beyer of Germany of the Swiss Federal Institute of Technology inserted genes from a daffodil (*Narcissus pseudonarcissus*) and a bacterium (*Erwinia uvedovora*) into rice plants to produce the modified grain, which has sufficient ß-carotene to meet total Vit-A requirements in a typical Asian diet [16]. If golden rice, currently still in the laboratory stage becomes a success in the field, it will help to strengthen the food-based approach to nutrition security. Whilst this breakthrough has not yet been commercialized, it is understood that the product will be clearly labeled as "vitamin A-enriched."

2. Iron enrichment

Iron-deficiency anemia is the most widespread nutrient deficiency in the world, affecting an estimated 2 billion people worldwide. Between 40 and 50% of children under the age of 5 in the developing countries are iron deficient and iron deficiency accounts upto 20% of all maternal deaths. It also impairs immunity and reduces the physical and mental capacities of people of all ages.

In short, iron deficiency is a major public health problem world wide with enormous social and economic costs. Rice fortified with iron was created through the introduction of proteins from the kidney beans Phaseolus vulgaris by the same researchers of Swiss Federal Institute of Technology [17]. It is reported that the iron content increased two folds in the modified crop, currently under testing stage. Indian scientists have also succeeded in enriching the rice grain with iron still under testing stages.

3. Golden mustard

Mustard (*Brassica juncea*) has been modified to contain high levels of a compound called beta carotene (pro-vitamin A) which is converted in the body to vitamin A. Golden mustard research is being pursued at TERI (Box 4). There is strong support that the oil can be processed into margarine or spread onto salad to meet the nutritional needs of the people.

The 'golden mustard', which is suitable to Indian tastes and climates, will offer hope to women and children who are currently beyond the reach of vitamin supplement programmes.

II. Designer potato

Advances in plant tissue culture techniques and gene transfer technology have opened up possibilities for modifying the amino acid contents of plants. Potato, which is the most important non-cereal food crop, ranks 4th in terms of total global food production, besides being used as animal feed and as raw material for the manufacture of starch, alcohol and other food products. This crop was genetically modified using a seed albumin gene Ama1 from *Amaranthus hypochondriacus* by researchers of Jawaharlal Nehru University (JNU), New Delhi, India [18].

The Ama1 protein is non-allergenic in nature and is rich in all essential amino acids. Its composition corresponds well with the WHO standards for optimal human nutrition [19]. The JNU team was able to use a seed albumin gene with a well-balanced amino acid composition as a donor protein to developing transgenic potato. The genetic enrichment of protein quantity and quality in potato can make a significant contribution to child and adult nutrition, since mashed potato can be fed to young children.

III. Fruits and vegetables

• The United Nations Food and Agriculture Organization rank bananas as fourth among the world's most important food crops. Bananas provide more than one-quarter of all food calories in Southern Asia. Onslaughts of pests and diseases had reduced the average yield of bananas to less than a third of the crop's potential. Scientists at TERI, using modern tissue-culture techniques, have succeeded in cultivating clean, pest-free banana plantlets that were distributed to smallholders. The yield of bananas improved dramatically and was seen as a viable cash crop generating income that could help raise living standards for many farm families.

• Transgenic crops could be invaluable to India for the production of vaccines. By combining pharmaceutical production and farming (as "pharming") vaccines can be produced cheaply and free of possible contaminating animal viruses that could become harmful to humans. The most expensive aspects of a

vaccination programme are the need for cold storage and needles. If vaccines can be produced in transgenic tomatoes or bananas, the requirement for cold storage and needles will be circumvented. Scientists are making impressive strides in this area. In addition, research is being carried out in India to use tobacco, an extremely hardy and drought-tolerant crop, to produce vaccines against the HIV. Many people are allergic to peanuts. The development of non-allergenic peanuts is important for India, as peanuts are a vital protein source in the diets of many Indians.

Hopefully we can look forward to more technological advances, not only to increase the nutritional quality of our food but also to effect improvements in food storage qualities and shelf life. There is little doubt that an integrated approach to conventional and modern breeding will be more effective in the future for any technology interventions and to bring it on the shelf. A bio-economic model can combine socio-economic factors influencing farmers` objectives and constraints with biophysical factors affecting production possibilities and the impact of land management practices.

CONCERNS AND RESPONSE

Like any new technology, transgenics have aroused public concerns about the biosafety and environmental impacts of genetically modified crops. A lot has been debated in Europe and elsewhere about transgenics and its backlash is on third world countries where it has impeded the progress of plant improvement programs. This leads to food insecurity, which then sets the chain of downward reaction leading to rising food prices, food riots and political instability. In an integrated world economy food insecurity and political instability in one region has repercussions everywhere. Biotechnology is one of the 'off shelf' technologies available today with us that can be made 'on shelf'. Slowing its acceptance is a luxury our hungry world cannot afford [2]. However, the public concerns are often genuine because no technology is completely risk-free and therefore we must weigh potential benefits against any possible adverse effects of the new technology on the environment and human and animal health in a holistic manner. It is absolutely essential that conscious efforts be made, especially to initiate well-defined programmes for the development and regulation of genetically modified plants. To make this possible and to ethically and sustainably reap the benefits of biotechnology, there is a pressing need for scientists, researchers, policy makers, NGOs (non-governmental organizations), progressive farmers, industrialists, and representatives of the government to come together on a common platform to discuss the following issues.

1. Environmental safety - Several beneficial crop plants have been and are being developed through transgenic technology. Risks are associated with genetically modified plants that are released into the environment, which in turn may have implications on biodiversity and ecosystem integrity. The nature of their interactions with other organisms of the natural ecosystems cannot be anticipated without proper scientific testing. These and many more doubts plague the minds of layman as well as decision-makers. There are concerns about the escape of transgenes to wild and weedy relatives and development of super weeds. These fears are however over exaggerated [20]. The possibility of genetic pollution is there although in most cases it is unlikely to happen because of the difficulty in hybridization between a transgenic crop plant and its weedy relative. Crops have been modified for disease and insect resistant that has been field tested and commercialized. There is not a single example of evolution of superweeds due to escape of resistance genes from crop varieties. Nevertheless, new approaches for transgene production will minimize the chances of escape of transgenes to wild populations. A novel technique to reduce transgene escape to wild species is to engineer, for example herbicide resistance into a crop chloroplast genome as has been demonstrated in tobacco [21]. Transgene cassettes could be developed which would harbour a selective disadvantage (e.g., dwarfing genes) for weed competitive ability.

2. Food safety and nutrition – Some of the frequently heard concerns are about the food safety of transgenic foods. Will the food from modified crops be safe to consume; could the presence of selectable markers genes such as antibiotic resistance genes have unforeseen effects on consumers leading to allergenic responses and will the food from modified plants have a different nutritional quality from that of the food it replaces. Selectable markers are now being developed which are completely benign such as mannose–6–phosphate isomerase (mpi) [22]. Improved transformation systems have been developed which allow the generation of marker free transgenic plants [23]. The development of 'Clean-Gene' technology (Box 5) seems to be the appropriate answer to all these apprehensions [24]. To date worldwide there have been no verifiable toxic or nutritionally deleterious effects resulting from the cultivation and consumption of products from GM crops. However absence of readily observable adverse effects does not mean that these can be completely ruled out and there has been no epidemiological monitoring of those consuming GM foods (GM Science Review, 2004 www.gmsciencedebate.org.uk). This calls for a more rigorous and in-depth biosafety studies over a long

period. However it is believed that safety assessment process will increase with the development of 'second generation' of GM crops. These crops and their products that are aimed to decrease levels of anti-nutritional factors (e.g. toxins and allergens) increase levels of health promoting factors (e.g. antioxidants) and modify levels of macro or micronutrients (e.g. proteins, lipids and vitamins) will be of greater significance.

3. Regulatory issues – There are many hurdles in the transfer of technology from lab to land and further on to the target population [25], the major being the regulatory issues. Issues like the appropriate labeling of the GM products and international legislation to ensure environmental protection being the key. Regulatory development all over the world lies with the government, which in turns tries to address the technology-inherent problems pertaining to transgenic. The intellectual property rights (IPR) surrounding the creation and ultimate deployment of transgenic is a key issue and cannot be isolated from the technological aspects of this endeavour. Issues of ownership, access and risk are fundamentally affected by the patenting of seeds by the private sector. Livelihood strategies such as seed-sharing (from seed banks) and the re-use of seeds over a number seasons are threatened when seed banks are controlled by commercial companies and smaller seed companies are bought out, reducing the availability of unpatented and non-hybrid seeds. Rural communities' self-sufficiency and security are potentially threatened by these new patterns of control [26]. Intellectual property regulations enable the genetic appropriation of unpatented seeds from around the world, to modify a single gene of these seeds and then patent and acquire exclusive rights over them. Ethical issues are thus gaining greater importance, as the extraordinary opportunities opened up by transgenics.

Over 25,000 field trails have been conducted on more than 60 crops in 45 countries and no long-term ill effects have been detected as evident from Crop database (WWW.AGBIOS.COM) on GM crops and their global status (Box 6). Approved GE foods are as safe as their conventional counterparts. Box 7 gives the actual status of GM Crop in Indian market. Ultimately consumers will decide whether the benefits of a new technology outweigh the notional risks. In the near future, GE crops, and foods derived from them will have higher levels of vitamins, appropriate minerals, and other nutrients. Many allergens will be eliminated. We are only at the beginning of these applications of biotechnology. Increased knowledge of plant's genomes will allow more rational approaches to plant breeding. Genetic modification and the emerging techniques of genomics offer the possibility of designing farming systems that are responsive to local needs and reflect sustainability requirements. Furthermore, as genome analysis becomes easier and cheaper, we will be able to tackle other underutilized crops, such as chickpea, sorghum, and millet that have not received much attention so far. Former US president Jimmy Carter said it so well "Responsible biotechnology is not the enemy; starvation is".

Technology is Available-Incentives are lacking

The results that came out from Sasakawa-Global 2000 from the last 15 years of research clearly states that;

- Food crop yields can be increased to dramatic amount with the technologies available on shelf.
- Good yield response to fertilizers is an achievable target across a broad spectrum of soil conditions.
- Farmers have shown great willingness and zeal to adopt and apply the high-yield crop technologies.
- Government extension officers, when given training, mobility and logistical support, are effective change agents.

(Source: Sasakawa-Global 2000-2002)

World Bank recommends that each country invest at least 2% of its agricultural GDP in agricultural research and development. Most countries fail to reach this level. In general the mix of private and public sector funded agricultural research in any country reflects the general type of political economy promoted by government.

In many eastern states of India some 55 to 60 percent of the people who live in rural areas are "absolutely poor", subsisting on less than US1$ per day. The region has the highest population growth rate and more than 200 million people suffer from chronic under nutrition. These situations have made the poor people of these states highly vulnerable to the attack from various diseases coupled with population pressure and natural calamities.

India has the potential to break the deadlock in its crop production and yield ceiling rate. Unfortunately still a large gap exists between potential and actual yields even with the technologies available on shelf. The gap is widened because of many folds as listed below;

- Over the last few years there has been some advocacy of a need for a pro-poor, pro-nature and pro-women bias in the development and dissemination of modern biotechnology's [27]. Agricultural biotechnology research is one among many, which could have differential and dramatic impacts on poverty alleviation. Many improved and a wide range of approaches to the biotechnological improvement are already

available or well advance in the research pipe-line that could be employed to raise the crop yields especially in low-income food deficit countries. However the current lack of focused public sector support for pro-poor agriculture biotech will make it unlikely for the poor farmers to have access to such technology in near future.

- Yields can be increased, provided political stability is restored, bureaucracies is broken, and their researchers and extension workers devote more energy to putting science and technology to work at the farm level.

- The technology is there but more relevant question is whether the poor farmers will be allowed and permitted to use this new technology. Small, but highly effective and well-funded anti-science and technology groups are slowing the application of new technology, whether it is developed from biotechnology or more conventional methods of agricultural science. Those who seek to deny small-scale farmers access to have improved seeds, fertilizers, and crop protection chemicals are from the affluent nations. Affluent nations can certainly afford to pay more for food produced by so-called 'organic' methods, not the poor farmers where most of the hunger and poverty prevails. Increase awareness of the issues and opportunities surrounding this agricultural biotechnology are a must.

- A major challenge facing public-funded agricultural biotechnology research which hopes to have rural poverty alleviation objective will be to improve the labour productivity of agriculture in a manner that does not lead to job displacement or loss of income among poorer rural groups. Development of technology that relieves farmer's time burdens in agricultural production (and household maintenance) without sacrificing their ability to earn independent incomes is therefore critical [28].

- For Plant biotechnology research to be better targeted to addressing the needs of poorer farmers, it will be necessary for relevant public sector institutions to more transparently identify with farmers' (or consumers') needs that are of concern to their research or funding agenda.

- In many public sector research organizations there is often an absence of demand-driven biotechnology research agendas especially in relation to the agronomic or socio-economic needs of poorer farmers [29]. Public funding is scarce.

- Within the broader agricultural research community there is a lack of priority-setting mechanisms and relative cost-benefit analyses to determine which available technological approaches may be the most suitable within particular time frames for addressing prioritized agronomic needs of the particular groups of farmers [30]. Farmer participatory needs assessments to determine research priorities prior to initiation of research and development.

- Plant biotechnology is failing to deliver goals to improve or empower poor farmer's livelihoods in many Indian states, as there is no linkage between farmers (participatory researcher) extension officers and plant biotechnologists. Also there is no integration between conventional breeding and agricultural improvement approaches. Biotechnology is here to complement conventional breeding but not to replace it.

- There is very limited access to the tools and germplasm necessary to apply high tech biotechnology research to the national needs of many institutional and academic bodies in India. The barriers to such access are many and mainly include lack of financial, scientific and infrastructure resources [26].

- Some Indian states do have limited biotechnology capacity in the areas of plant tissue culture and micropropagation. Some do not have these basic infrastructure and facilities. State bodies, which have the capacity and resources to generate transgenic plants, are struck as the mechanisms to ensure that the plants can reach the end user (i.e. the farmer) are lacking [31].

- Inadequate incentives and few financial packages for the scientists who have got themselves enriched with the knowledge and power of molecular and biotechnological tools to return to conduct research in their respective countries is still a distant dream. In the absence of public sector funding for such scientists upon return, it is likely that many such scientists will become technology adapters and/or marketing agents for imported proprietary products/germplasm developed by private and non-domestic companies. 'Brain drain' still jeopardizes chances for country like India. As and when such scientist return to situations where there is no or very little conventional plant breeding activity or infrastructure, the comparative advantage that

they have learnt in plant biotechnology cannot easily be applied to the improvement of agriculture in their own countries [32]. The 'Knowledge' acquired by them then becomes rust.

CONCLUSION

Mankind simply cannot afford to ignore the huge benefits plant biotechnology can bring to the cause of sustainable agriculture in developing countries where most of the poverty-stricken people live. The first priority for biotechnology in these countries should be to deliver prosperity to farmers [33].

Concerns about productivity alone will not achieve this. Agriculture needs to be transformed from culture (empirical) to technology (less risk prone). Socio-economic concerns cannot be ignored during the application of biotechnology. However there can be no lasting solution to the hunger/poverty and food problem unless there is a balance struck between food production/distribution and human population growth.

We must be environmentally responsible in our efforts to produce more quantities of food to feed the ever-growing population. But we must also face the fact that we cannot turn back the clock and use technologies that were adequate for a much smaller world population. Scientific progress is a continuum and progress will take place so long as the spirit of innovation and invention is not stifled.

There seems to be a growing fear of science as the pace of technological change increases [34]. Science values originality as a mark of greater achievement. The poet William Blake said, "What is now proved was once only imagined". Imagination and vision are the very heart of the scientific enterprise. We must provide not only finished products but also the technologies that will enable a new generation of researchers to solve the food security challenges of tomorrow [35].

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Box 1- Micropropagation Technology Park (MTP) at TERI

India has pioneered a number of discoveries in the field of plant tissue culture. Unfortunately, most of these have remained confined to the laboratory and have not been fully utilized for commercial benefit. To bridge this gap between research and field, in 1989, the DBT set up a sophisticated pilot-scale laboratory at TERI's 36-hectare campus in Gual Pahari, Gurgaon, Haryana. In 1997, this laboratory was upgraded into an MTP (Micropropagation Technology Park) under a project sponsored by the DBT. At the MTP, all the infrastructural facilities, ranging from modern laboratories and greenhouses to nurseries, required for mass production of plants is available.

Highlights

- More than 13.0 million plants of various species have been dispatched from the facility to forest and horticulture departments, Spices Board, NGOs, agro-based companies and other progressive growers.
- Field evaluation at various locations confirms high survival, and better growth rates of tissue cultured plants as compared to conventional propagules.
- Transferred technologies to the industry for commercial exploitation.
- Trained several researchers, foresters, students and entrepreneurs in commercial tissue culture.

Box 2- Development of New Cultivars in Rice using MAS

To cite an example of MAS breeding program, a research project was initiated with an industry partner to develop genetic markers associated with heritable factors that influenced rice cooking and processing quality (www.usda-ars-beaumont.tamu.edu). DNA (genetic) markers were identified that were associated with various forms of the rice starch synthesis gene which controls amylose content of the grain. The amount of amylose in the grain is the predominant factor in determining the softness/firmness of cooked rice. This trait is usually not evaluated until after several generations of self-pollination in the breeding process when excess seed is available. Having a genetic marker associated with this gene allows one to identify the desired form of the gene (allele) from the onset of the selection process using DNA from most any tissue on the plant. This technology enabled to rapidly identify genetic lines that had the desired amylose allele and discard those without. The outcome was the development of two new cultivars, Cadet and Jacinto, which have unique cooking and processing quality. Where it generally takes 7-10 years to develop a cultivar, marker assisted selection decreased the development time of these cultivars by several years. Also, the marker technology will provide a more accurate assessment of amylose content than the analytical methods previously used.

Box 3- Genetic Modification: What One needs to know

What is GM?

The science of GM as given in the BBC web site (www.bbc.co.uk)

"Genetic modification involves altering an organism's DNA, the blue print of life. This can be done by altering an existing section of DNA, or by adding a new gene altogether. A new gene can be added from one individual to another from the same species, e.g. tomato gene into another tomato plant, or between individuals from two different species, e.g. tomato gene into a fish. It's possible to transfer genes from one species to another from plant to plant, from animal to plant, from plant to animal or from animal to animal. This is because all genes, no matter where they come from, are made of the same material – DNA".

Why GM debates?

The public, scientists and policymakers at a series of conferences and discussion are debating the prospects of GM. The aim is to listen to the public's view before deciding whether to license GM crops or not. To realize the full potential of GM, proper testing and scientific data have to be provided and made more transparent and open. To bring all the issues subjecting to GM in an open forum, debates and reviews serves as PR exercise.

Where does the India fit in?

India is well poised to join the race with regard to GM crops along with China and US. Initiatives have been taken to promote transgenic research in plants with emphasis on pest and disease resistance and nutritional quality. Necessary guidelines for transgenic plants have also been evolved. A strong base of indigenous capabilities has been created. The field of GM crops would form a major research and commercial endeavor for socio-economic development in the next millennium.

Is GM bad for us?

Till date there is no evidences to support that food derived from GM crops are harmful in anyway to our health and safety. However GM is still in its infancy stage and critics say not much is known about its potential dangers.

Box 4. Golden Mustard –A Case Study in TERI, India

Statement of the problem
The intake of vitamin A in the diet of deficient populations can be increased by supplementation, fortification or development of carotene rich foods. Supplementation and fortification programs have done much to relieve VAD, and will continue to provide needed nutritional supplements [36]. However these two approaches alone cannot solve the problems caused by micronutrient deficiencies (Harvest Plus, 2003 www.harvestplus.org) hence it calls for biotechnological interventions. As opposed to the recent past, the new techniques offer an effective, timely and scientifically feasible means to enhance the carotenoid contents of common foods in a targeted and sustainable approach.

Mustard as choice of crop
The choice of enhancing –carotene in mustard oil is for multifold reasons

- Attractive delivery mechanisms
- Preference for food-based delivery system
- Value-added yet economical source of nutrition
- Meet with the existing demand for mustard oil.

Science of GM mustard
To understand the technology behind the development of golden mustard one has to look the bi-centric part of beta-carotene. Biosynthesis of beta-carotene occurs in the plastids and geranylgeranyl diphosphate (GGDP) is the precursor molecule. Phytoene synthase (*psy*) is the first and rate-limiting enzyme in the β-carotene biosynthesis pathway. The strategy to enhance β-carotene in seeds of mustard was to increase the levels of phytoene synthase and phytoene desaturase (*crt*) specifically using napin promoter wherein the enzymes are directed to the plastids using a transit peptide.

TERI success and achievements
The Energy and Resources Institute (TERI) in India has two decades of experience in mustard improvement both by conventional and molecular approaches. Hence it was decided to take the 'proof-of-concept' from Monsanto to develop –carotene enhanced mustard varieties.

Box 5- 'Clean Gene' Technology

Transgenic technologies are key to plant molecular genetic studies and crop improvement strategies, potentially offering worldwide benefits. Important limitations, however, lie in the uncontrolled factors affecting the integration and behaviour of transgenes. Strategies to control transgene integration and to limit unwanted or multiple integrated DNA sequences are central to the development of future plant transformation technologies. Among these, the production of marker-free transgenic plants is particularly important.

DFID funded research at the Norman Borlaug Institute (NBI) and John Innes Centre (JIC) has been successful in finding a way of producing transgenic crops that are free of undesirable selectable marker genes (such as antibiotic resistance genes) and containing simple transgenic loci [24]. This overcomes a constraint to the employment of genetic engineering: the perceived risks from introducing antibiotic resistance genes, which are only included because they are part of the transformation process, into the genetically modified crop.

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Box 6. Global Status of Approved Genetically Modified Plants
(Source: AGBIOS)

Crop database (WWW.AGBIOS.COM) on GM crops provides complete descriptions of each of the events that have received regulatory approval in one country atleast worldwide. The database includes not only plants produced using recombinant DNA techniques (e.g., genetically engineered or transgenic plants), but also plants with novel traits that may have been produced using more traditional methods, such as accelerated mutagenesis or plant breeding.

Box 7. GM Crop in Indian market

Is it likely I will eat GM food in India?
The biosafety regulation in India was set up in 1998 by DBT. Till date no commercial food crop has hit the Indian market. The only crop that has got the approval from the biosafety statutory bodies is *bollgard* cotton. However, there is all possibility that in few years' time GM food will be consumed as processed foods, meat and poultry and hard cheese. Consumer acceptance will play a very major role.

Prospects of *GM crop in near future*
GM research is still in its infancy stage in India. However the results from various GM crop trials in India carried, as Farm Scale Evaluation will be known, outlining the environmental impact of growing GM rice, oilseed rape, potato etc. If the evidences are positive–or even inconclusive – such crops could be licensed and grown commercially.

Will this create an inundation of GM foods?
This will largely depend on consumer acceptance. There is no doubt that GM's real potential lies in Third World, where the technology could be used to make rice and other staple crops more nutritious; to help crops withstand to extremities of different biotic and abiotic stresses and to produce life saving drugs in crops against diseases.

Likely GM food products
Processed foods – Under ISBC (Institutional Biosafety Committee) and RCGM (Review Committee on Genetic Manipulation) all food crops needs to be labeled 'GM' or 'modified'. However, 'derivatives' of these crops don't have to be labeled in case the altered DNA has been processed out of the product. Nor do GM ingredients have to be declared when present in very small quantities (less than 1 per cent).

Chances of GM food abroad?
Worldwide 16 countries grow and eat GM foods, among them USA, Argentina and China are the key players. In the US, it is hard to avoid GM ingredients in a meal as almost all food-based products contains either soya or maize that occupies 75% of the crop planted.

Table 1. Smallholder advantage from *Bollgard* insect-protected cotton.

	Conventional Cotton	*Bollgard* Insect-Protected Cotton	Average Smallholder Advantage with *Bollgard*
Pest Resistance	NONE	American bollworm Spotted bollworm Pink bollworm	
Insecticide Sprays Per Season	Four (4)	One (1)	-3 Sprays
Average Yield Per Hectare	833 Kg	1,501 Kg	+668 Kg
Income Advantage Per Hectare	NONE	US$30	+US$30

Table 2. Commercialised GM crops available in global market

Crop Name	**Phenotypic Traits**
Canola	Phosphinothricin (PPT) herbicide tolerance; modified fatty acid content
Carnation	Increased shelf-life; modified flower colour
Chicory	Resistance to lepidopteran pests
Cotton	Resistance to lepidopteran pests; herbicide tolerance
Maize	Herbicide tolerance; Resistance to corn borer
Melon	Delayed ripening
Papaya	Resistance to viral infection
Potato	Resistance to potato beetle; potato virus
Rice	Herbicide tolerance; resistance to disease and pests
Soybean	Modified seed fatty acid; herbicide tolerance
Tomato	Delayed ripening; resistance to lepidopteran pests
Squash	Resistance to viral infection
Sugar Beet	Herbicide tolerance